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REMARKS ON THE QUANTUM-FIELD THEORY OF MATTER
THE PROBLEM OF THE UNIFIED-FIELD THEORY

Ya. I. Frenkel'

Quantum Mechanics and the Corpuscular Nature of Matter

In present-day quantum mechanics the various particles, just as the system of interacting particles, are described statistically in a completely identical manner, by the wave function in the configurational space of the system.

Therefore, because all particles, which in principle are localized in space and time, are considered invariable, such a statistical description actually means a rejection of physical determinism in any determination of the particles' motion.

Foreign physics, in evolving idealistic views and basing itself on the analysis of the observer's role in his action on the system under investigation, constructed this indeterminism into the theoretical basis of quantum mechanics. In the past years Soviet physicists and theoreticians have attempted in their work, proceeding from materialistic positions, to overcome indeterminism in the course of events, and to reduce indeterminism to indefiniteness, which is inherent in the quantum-mechanical determination of the initial states.

I propose that the essence of the problem is not in this but in the fact that the purely corpuscular-model construction of matter, which has been used up to the present, is in reality inadequate when one talks about the so-called microcosm (this viewpoint was expressed for the first time by the author in a public lecture at the Academy of Sciences USSR in 1947), since the microcosm mirrors only the corpuscular aspect of matter without taking into consideration the microcosm's wave nature.

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Limited Divisibility of Matter

In an analysis of the nature of matter, the philosopher-materialist of old considered that macroscopic solids consisted, as with gases, of discrete particles, namely, atoms, which can be considered as small, hard bodies differing from ordinary solids only by uniformity and compactness. This latter assumption did not in any way prevent one, however, from treating these small solids as being composed of still smaller particles strongly cemented together; that is, from subdividing these atoms still further into still smaller elements, although imaginary, proceeding in this direction indefinitely.

Physicists at the beginning of this century did not diverge far from the ancient philosopher in this problem, only sharpening their representations concerning the so-called atoms. Among these were included electrons and nucleons, which were ascribed with definite size and even form; that is, these particles, just as by the ancient Greek philosophers, are considered as miniature solids which are practically incapable of further subdivision but theoretically able to be subdivided indefinitely into still smaller elements. During nonuniform motion of the electron and its variable relative disposition of its elements, the interaction of these elements of the electron with each other causes a resulting force of self-action in the electron; that is, action upon itself which results in the main in an inertial force. How seriously physicists concerned themselves with the theoretical divisibility of the electron is clear from the numerous attempts to ensure the stability of the electron relative to disintegration under the action of electrical forces of mutual collision between the electron's elements, by employing forces of this or that type of a nonelectrical nature able to balance them (as done by Poincare, Mie, and others).

All these attempts proceed from naive mechanical concepts concerning the nature of these basic elements of matter and the character of their motion, namely, representations copied from macroscopic objects.

Limitation of the Purely Corpuscular Representations; Field Theory of Matter

The development of the theory of quanta posed next the problem concerning the decisive rejection of these mechanistic views.

First of all, experience showed that the basic, in essence metaphysical, representation of the theory of matter in classical physics -- namely, the representation concerning the "solidity", or, more accurately, the invariance of its fundamental elements (electrons and nucleons) -- does not correspond with actuality.

We now know that electrons are not eternal, but can, with the conservation of total energy, appear and disappear together with their opposites, the positrons, in the same manner as light disappears during absorption and appears as light quanta during emission of photons.

We possess very convincing reasons for thinking that heavier particles, namely nucleons, likewise turn out to be variable when subjected to energies higher than one million volts, which are necessary for the creation of nucleon-antinucleon pairs. (Note: At present, we are familiar only with the fact of the mutual interchangeability of protons and neutrons within the nucleus with the simultaneous emission or absorption of an electron or positron and neutrino.)

In each case, the law of the conservation of matter in its original classical sense, that is, the law of the preservation of elementary particles of which matter is composed, can be considered as experimentally refuted.

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This fact cannot be considered as a threat to the law of conservation of matter. Obviously matter is conserved together with its existing properties, namely, energy, mass, momentum, angular momentum, etc. What is not true is that matter consists of immutable elementary particles. This old, purely corpuscular metaphysical model of matter must be abandoned and be replaced by new representations based on the capacity of matter to exist not only in the corpuscular form but also in another noncorpuscular form.

This proposition is not new. In theoretical physics it appeared more than 20 years ago. Here we call this second phenomenon of the nature of matter wave, or, more generally, field. Waves or fields with which we are concerned are like the ordinary classical ones, for example, electrodynamic ones, only in the following sense: they are propagated in space continuously. However, the actions of their wave fields appear in the form of discrete quantum effects which we represent in the simplest case in the form of individual particles. Thus the new quantum fields represent an unusual dialectic entity of space-time continuity with the discreteness or quantum nature of action, namely, an entity for which physicists were unable until not to devise any other model than the model of classical waves on the one hand, and classical particles on the other.

This concept is inadequate in the following respects: the corpuscular and wave aspects of matter act as if equivalent. Actually, as we know, particles or quanta, which are connected by the particles with the field representation, can appear and disappear for suitable energy conditions, individually or in pairs, while the field basis of matter, if it does vary, in any case cannot completely disappear; actually the field is merely the fundamental concentrated dynamic properties of matter, that is, its energy, momentum, etc.

Elementary Particles as Field Quanta

The nature of the discussed relations is, in a certain measure, covered by the classical theory of the electromagnetic field. In this theory, according to Lorentz, the field itself is the bearer of the dynamic properties of electrified matter, that is, the field and not the charges particles, which ordinarily are treated as the source of the field. If the sum of the self-interaction, that is, the force which the electron exerts on itself, and the external force which it sustains from the other particles is set equal to zero, then the electron's motion will proceed in accordance with the Newtonian laws, or, more accurately, with Einstein's relativistic mechanics.

In this case, the energy, momentum, and angular momentum which were earlier affixed to the electron turn out to be properties of the electromagnetic field and satisfy the conservation laws. Under these conditions, it is essential to consider the electrons and positrons not as sources of the electromagnetic field but as its products, thus abandoning, on the one hand, the forces of interaction or the so-called self-action and considering, on the other, their displacements and shifts in space and time as the result of variations in the field, in accordance with the law of conservation of energy, etc.

This program, planned by Lorentz about 50 years ago, has still remained incomplete up to now because of the so-called problem of the internal structure of the electron, with the electron considered as a small hard solid.

At present, after a half century of development of the quantum theory, we must establish a new basis for this fundamental problem and re-examine it all over again.

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With this new point of view, electrons and positrons cannot be considered in the sense as small hard spheres but as special kinds of quantum of an electromagnetic field. These quanta cannot, of course, be confused with photons, which correspond to the energy of the field, and then only in the wave zone.

The fact that all electrons are identical, relative to their charge and rest mass, becomes obvious from the new point of view, because they all correspond to one and the same field. The problem concerning the divisibility of each electron into infinitely small elements and the interaction of these elements with each other loses any sense. Quanta of electrified matter, with mass at rest different from zero, also are deprived of any internal structure, just as quanta of light have none; the rest mass of light quanta equals zero.

As is well known, nucleons that form complex nuclei are also connected with a certain nucleonic field, being the field's quanta; in this case what corresponds to the energy and the momentum of this field are obviously the mesons, namely, charged particles playing the same role relative to energy and momentum as the photons play relative to the electromagnetic field

This problem requires further development in connection with the existence of mesons with various masses to which obviously correspond various states of one and the same field system.

Without going deeply into these still unsolved problems, we can, however, assert with complete assurance that the laws of macrophysics, therefore, differ from the laws of microphysics and that the objects of microphysics are not the ordinary particles for which the classical laws were formulated but are forms of matter that differ qualitatively from them; they are quantum fields, that is, fields that are continuous in space and time and that appear in the form of discrete effects, which are connected with model representations concerning particles, although these model particles are invariable.

Mechanical materialism in contrast to dialectical materialism considers from all forms of motion, in the widest sense of the word, only one simplest form, mechanical motion. Until recently it appeared to many physicists that in the field of mechanics, and particularly in quantum mechanics, this simplest form of mechanical motion and the determinism connected with it are the only possible ones. But now the mechanistic picture of the world suffered a fiasco; the microphysical processes lost their mechanistic character and acquired a character more general and complex, which we could call quantum field, or corpuscular field.

Foreign physicists see a way out from the difficulties connected with the old, purely mechanistic concept of matter only in the denial of determinism and cause; that is, they finally denied materialism. In contrast to them, Soviet physicists must seek the solution of the problem in the continued development of theoretical physics on the basis of the philosophy of dialectical materialism. The main direction of future work, in the opinion of the author, is the construction of a unified field theory of matter, or monistic field theory of matter.

Fundamentals of the Unified-Field Theory of Matter

In present variations of the field theory of matter, this theory is considered as a combination of quantum fields on the one hand, and particles on the other, in which the energy of the entire system is connected partly with the field and partly with the particles, and finally with the interaction of field with particles. This dualistic treatment leads to retention of all those theoretical difficulties which are peculiar to the purely corpuscular theory, thus leading particularly to diverging or indefinite expressions for the energy,

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mass, etc. I propose that these difficulties are rooted in the purely corpuscular appearance ascribed to matter, which is considered merely as a set of particles, and that these difficulties can be eliminated only by a complete and decisive rejection of the narrow corpuscular representations. The representation of particles as quanta of a field does not require an independent self-contained basis. The representation of a quantized field must be its own basis.

The field itself is considered in two forms of its phenomenon, whereas the concept of particles in the classical sense of the word is not considered at all. This means that all dynamic properties of matter earlier attributed to particles and up to now associated with particles, for example, mass, energy, momentum, etc., pass over wholly and completely to the field. Under these conditions the very name of the physical science of matter and motion must be changed so that the word mechanics would be completely eliminated and the presently used name quantum mechanics replaced by the name quantum-field theory.

I propose that the outlines of this theory have been correctly drawn by me and that knowledge of the true nature of matter lies on this nonmechanical path.

It is only in this way that we shall solve the above-stated problem concerning the overcoming of indeterminism. The quantum-field theory is strictly deterministic. The apparent indeterminism appears in the quantum theory only when we attempt to reconcile the field and corpuscular description of phenomena. In the quantum-field theory, such comparisons turn out to be possible only on a purely statistical basis, that is, on the basis of the theory of probability. This circumstance does not concern in any way the determinism of physical phenomena considered from the quantum field point of view.

Revision of Corpuscular Theory in Light of Quantum-Field Theory

In concluding, I wish to refer briefly to two articles which I have published earlier and which are devoted to clarifying certain peculiarities of the corpuscular treatment of matter in connection with the theory of relativity but without consideration for the field theory: "Relativistic Quantum Mechanics of Complex Particles," Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, 1947 and "Theory of Motion of Particles in Relativistic Quantum Mechanics," Doklady Akademii Nauk SSSR, 1949. From the purely corpuscular, obviously incorrect, point of view, it is essential that one thoroughly review and study the deviations of the quantum theory from the classical representations concerning the motion of invariable materialistic particles.

Because elementary particles can disappear and again appear, it is essential to consider the processes in which these particles are apparently conserved as regenerative, in the sense that the motion of a particle in space can be described as a disappearance of the particle in the original place and an appearance in another place more or less close to the original location. Such an interpretation results directly from the motion of the electron in Dirac's relativistic theory.

As Schroedinger showed, in considerations of the speed of an electron moving relative to inertia, one detects, along with a constant component velocity, a component velocity with frequency equal to $2m_0c^2/h$ which velocity is connected by Schroedinger with the passage of the electron from the state of positive energy to the state of negative energy.

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If the nonexistent states of negative energy are replaced by positrons, then this result can be interpreted as the appearance, in the neighborhood of the electron under consideration, of an electron-positron pair, in which case the positron is annihilated along with the original electron, which turns out to be replaced by a new electron in a new position. In the case of particles with a finite rest mass, such generation of a particle must be observed in an infinitely close position in agreement with the classical representation concerning the continuity of motion; in the case of photons which possess no rest mass, the concept of trajectory of a particle loses any significance.

(Editor's Note: Study of the field as one of the forms of matter has become one of the most urgent problems of contemporary physics. Many scientific investigations have been devoted to the development of the field theory. At present, Soviet scientists are working on the field theory. Besides this article by Ya. I. Frenkel', the editors of this publication are also printing another article devoted to the field theory, namely, D. I. Blokhintsev's "Elementary Particles in a Field," appearing in this same issue of Uspekhi Fizicheskikh Nauk. In these articles the authors approach from different directions the same viewpoint concerning the unified-field theory of matter. Obviously this is still not a real theory but only an attempt to establish the necessity for this theory. Furthermore, not all of the even fundamental facts are considered in the light of the new ideas and not all the suggestions can be considered indisputable. The editors of this journal are willing to publish further general discussions of this problem or individual ideas expressed by the authors of these two articles.

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